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Knowledge about a common source can promote visual – haptic integration

Hannah B Helbig, Marc O Ernst
Max Planck Institute for Biological Cybernetics, Spemannstrasse 38, D 72076 Tübingen, Germany;
e-mail: helbig@tuebingen.mpg.de
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Abstract. The brain integrates object information from multiple sensory systems to form a unique representation of our environment. Temporal synchrony and spatial coincidence are important factors for multisensory integration, indicating that the multisensory signals come from a common source. Spatial separations can lead to a decline of visual – haptic integration (Gepshtein et al, 2005 *Journal of Vision* **5** 1013 – 1023). Here we tested whether prior knowledge that two signals arise from the same object can promote integration even when the signals are spatially discrepant. In one condition, participants had direct view of the object they touched. In a second condition, mirrors were used to create a spatial separation between the seen and the felt object. Participants saw the mirror and their hand in the mirror exploring the object and thus knew that they were seeing and touching the same object. To determine the visual – haptic interaction we created a conflict between the seen and the felt shape using an optically distorting lens that made a rectangle look like a square. Participants judged the shape of the probe by selecting a comparison object matching in shape. We found a mutual biasing effect of shape information from vision and touch, independent of whether participants directly looked at the object they touched or whether the seen and the felt object information was spatially separated with the aid of a mirror. This finding suggests that prior knowledge about object identity can promote integration, even when information from vision and touch is provided at spatially discrepant locations.

1 Introduction

We use multiple sources of sensory information to perceive our environment. For instance, the size or shape of an object can be judged on the basis of visual as well as haptic cues. When the object is simultaneously seen and touched, the brain integrates the redundant sources of information across sensory modalities to come up with the most reliable estimate (Ernst and Banks 2002; for a review see Ernst and Bülthoff 2004). This is achieved by weighting the sources of information according to their reliability (more weight is given to the more reliable source).

Bimodal integration depends on structural similarity between the bimodal sensory input, such as the degree of temporal synchrony (eg Choe et al 1975; Jack and Thurlow 1973; Klemm 1909; Radeau and Bertelson 1977, 1987; Thomas 1941) or the amount of spatial separation (eg Bertelson and Radeau 1981; Choe et al 1975; Thurlow and Jack 1973). Temporal synchrony and spatial coincidence are strong cues indicating whether two signals refer to the same object or event and should therefore be integrated. Several researchers investigated the biasing effect of one modality on another as a function of spatial separation between the sensory sources (eg Gepshtein et al 2005; Jackson 1953; Warren and Cleaves 1971; Witkin et al 1952). They found that integration subsides with large discrepancies between object properties, which renders it likely that the signals arise from different sources.

Besides structural properties, prior knowledge about a common source may promote integration. In agreement with this hypothesis, some classic cross-modal phenomena (eg prism adaptation, ventriloquism) have been shown to depend on the participants' belief that samples arise from the same object ('unity assumption'—Welch and Warren 1980) (for a review, see Bedford 2001; Welch and Warren 1980). For example, Miller (1972) demonstrated the influence of instructions about object unity on the relative contribution of vision and touch to the perceived shape. Similarly, Welch (1972) has shown that whether or not prism adaptation occurs depends on the participants' belief that differing information (seen and felt position of the hand) came from the same object (hand). However, when participants looked at their own hand through displacing prisms and were misled to believe that they saw someone else's hand, prism adaptation was impaired. Another study demonstrating the effectiveness of the unity assumption on multisensory integration was conducted by Warren and colleagues (1981). They presented participants with spatially discrepant visual and auditory signals and studied the effect of task-irrelevant visual or auditory information on the perceived location of the signal in the target modality. The intersensory bias was larger when participants were instructed that visual and auditory information come from a common source (Warren et al 1981). However, there are other studies in which no influence of task instructions on object identity was found. For example, Radeau and Bertelson (1974, 1978) did not find any difference between adaptation aftereffects observed when participants were told that the origin of the visual and auditory input was either the same or different.

Besides instructions whether two signals arise from a common object, the realism of the display was considered as a factor influencing the strength of the unity assumption. A number of researchers (eg Jack and Thurlow 1973; Jackson 1953; Thurlow and Jack 1973) observed that integration is stronger in more compelling stimulus situations that enhance the strength of participants' unity assumption (for a review see also Welch and Warren 1980). In contrast, Radeau and Bertelson (1976, 1977) did not observe any influence of the realism of the display on aftereffects of ventriloquism.

In summary, it remains controversial whether prior knowledge that two signals emanate from the same object can promote multisensory integration. Therefore, the present research was set up to address this question. Experiments 1 and 2 were aimed at demonstrating that spatially discrepant visual and haptic signals are integrated when participants have a good reason to assume that the two signals provide information about the same object. Experiment 3 was conducted as a control to verify that, in the absence of auxiliary knowledge about a common source, integration actually breaks down when the multimodal signals are spatially discrepant.

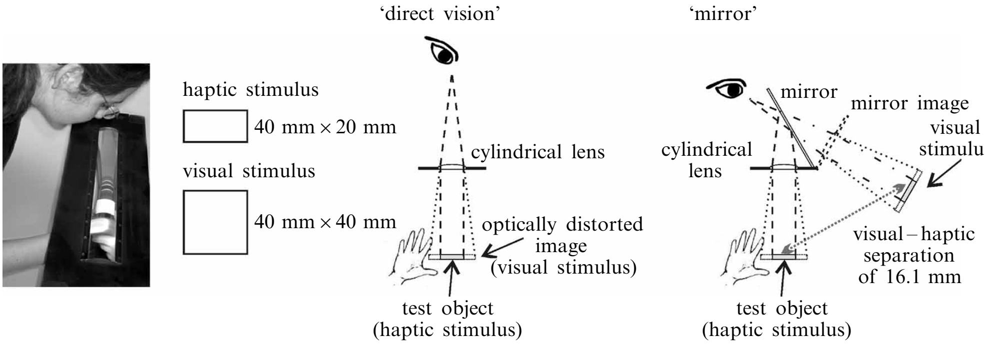
2 Experiment 1

In the first experiment we tested whether prior knowledge that two sensory signals originate from the same object facilitates integration even when the two signals are presented at discrepant locations. In one condition, participants directly looked at the object they touched ('direct vision'). In the second condition, we used mirrors to produce spatial separations between the visual and the haptic object ('mirror' condition). Previous research has shown that integration effects gradually decreased as the spatial separation between the signals increased (eg Gepshtein et al 2005; see also experiment 3). However, in the present experiment, participants were allowed to see the reflection of their hand grasping the object and the mirror itself, which creates a strong impression of unity, ie participants believed that the visual and haptic stimuli were emanating from the same object. If the knowledge that what we see is what we feel is sufficient for integration to occur, even in the case of spatial discrepancy, we would expect to observe a mutual biasing effect of vision and touch that does not differ across the 'mirror' and 'direct vision' conditions. If, however, integration is immune to such unity knowledge, and is only based on spatial and temporal coincidence, the effect of integration should be diminished in the mirror-viewing condition. To assess the relative contribution of vision and touch to the combined shape percept we presented slightly conflicting visual and haptic shape information in both the 'mirror' and the 'direct vision' condition. We introduced this shape conflict by having participants look at the probe object through a distorting lens. Participants were asked to report the perceived shape by selecting a match from among a set of comparison objects that they could either see or feel (visual or haptic matching).

2.1 *Method*

2.1.1 *Participants.* Forty-eight participants, thirty-one males and seventeen females, with normal or corrected-to-normal vision participated in the experiment. They were randomly assigned to one of two groups, one that haptically selected comparison stimuli to report the perceived height (haptic matching task), and one that visually matched comparison stimuli (visual matching task). All participants were naive to the purpose of the experiment. The average age was 28 years (range 14 – 49 years). Participants gave their informed consent before taking part in the experiments, which were performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

2.1.2 *Stimuli and setup.* The methods applied here were similar to a classic study conducted by Rock and Victor (1964). The visual – haptic standard stimulus was a white plastic rectangle of 40 mm × 20 mm. Its thickness was 2.0 mm. The experimental setup is illustrated in figure 1. Participants viewed the standard stimulus through a transparent plano-convex cylindrical lens, which expanded the image in one dimension only, so that the image was distorted. The distorting lens was fitted into the top of a box (see figure 1) that prevented direct sight of the stimulus. The amount of expansion depends on the distance between the eye, the lens, and the object. The probe object was rigidly mounted below the lens by means of a vertical rod attached to the midpoint of the lower surface of the rectangle. We adjusted the distance between the participants' eye, lens, and stimulus such that the virtual image was a square measuring 40 mm on each side. A head-and-chin rest stabilised the head position. Participants were instructed to grasp the stimulus from below, at the edges and corners, with thumb and index finger of the dominant hand. They were told to actively explore the stimulus by grasping the object several times from different directions. The experimenter ensured that participants followed the instructions to look and feel simultaneously. In the 'direct vision' condition participants directly looked at the stimulus through the lens, and thus viewed and felt the stimulus at the same location. To manipulate the spatial



(a) (b)

Figure 1. Schematic illustration of the experimental setup. (a) Participants view the test object through a cylindrical lens while grasping it. Visual shape is optically distorted and thus differs from the haptically specified shape (sensory conflict). (b) In one condition ('direct vision') participants directly look at the visual stimulus. Visual and haptic stimuli are spatially coincident. In the 'mirror' condition, participants view the visual stimulus through mirrors. Thus, visual and haptic stimuli are presented at discrepant locations. Participants see the mirror image of their hand grasping the object. Therefore, they know that visual and haptic sensory inputs emanate from the same object.

location of the visual stimulus we used a mirror ('mirror' condition). The mirror was mounted on top of the viewing box. The mirror surface was slanted by an angle of 61° relative to the surface of the rectangle (see figure 1b). Thereby the mirror image of the visual stimulus was displaced from the physical object (haptic stimulus) and thus created a visual–haptic spatial separation of about 16.1 cm. The angle between surface normals of the haptic and the displaced visual rectangle was 58°. Because participants were familiar with mirrors and because they saw their fingers exploring the object in the mirror, they had good reason to believe that both sensory inputs originated from the same physical object.

For the matching task, we used a set of 8 rectangular comparison stimuli. They all had a width of 40 mm and a height ranging from 16 to 44 mm (in steps of 4 mm). The thickness of the comparison rectangles was 2.0 mm. Comparison stimuli were attached to rods and mounted in a row on a black panel in the order of their size.

2.1.3 *Procedure.* To prevent any learning, each participant performed only one trial in each of the two conditions ('direct vision' and 'mirror'). The order of conditions was counterbalanced across participants. We presented the same standard stimulus in both conditions. Participants were not aware of this, because they had to leave the experimental room between the two trials they performed, so that the experimenter could, in principle, have exchanged the test object. No feedback was given throughout the experiment. Each trial consisted of an exploration phase and a matching phase. The participants were instructed to inspect the stimulus until they had a good idea of its shape (width-to-height ratio). The participants were then asked to match the target object by selecting a comparison stimulus that matched the shape of the previously examined standard immediately after they explored it. Half of the participants viewed the comparison stimuli without touching them (visual matching). The others haptically matched the comparison stimuli but were not able to see them (haptic matching). Participants have neither seen the comparison objects before, nor knew in advance whether they would be asked to perform a visual or haptic matching task. Participants judged the shape (width-to-height ratio) of the probe object. In all experiments participants had to match the height of the object, as the width was always the same. Our measure was therefore perceived height.

2.2 *Results and discussion*

Figure 2a shows that the perceived shape (height) was in-between the visually (40 mm) and haptically (20 mm) specified shape. None of the two sensory modalities completely dominated the bimodal percept. Instead, we found a mutual bias in both the visual and haptic matching tasks, indicating that a combination of visual and haptic shape information is used for the task. A repeated-measures ANOVA was conducted with within-participants factor vision ('direct vision' and 'mirror') and between-participants factor matching (visual versus haptic matching).

Interestingly, the analysis revealed a significant difference between visual and haptic matching ($F_{1,46} = 12.822$, $p < 0.001$). The perceived shape was biased more towards the visually specified shape when participants visually matched the standard stimulus to a comparison. When participants selected the comparison object haptically, relatively more weight was given to the haptic modality, ie the matched shape was closer to the haptically specified size. If the signals were completely fused, one would have expected the reported shape percept to be the same, independently of whether the matching task was visual or haptic. However, this is not what we have found, although our finding is in full agreement with other reports in the literature. For example, Hershberger and Misceo (1996) asked their participants to judge the size of plastic squares that were optically distorted so that the visual size was half the haptic size. In both experiments, ours and theirs, participants did not know in advance which type

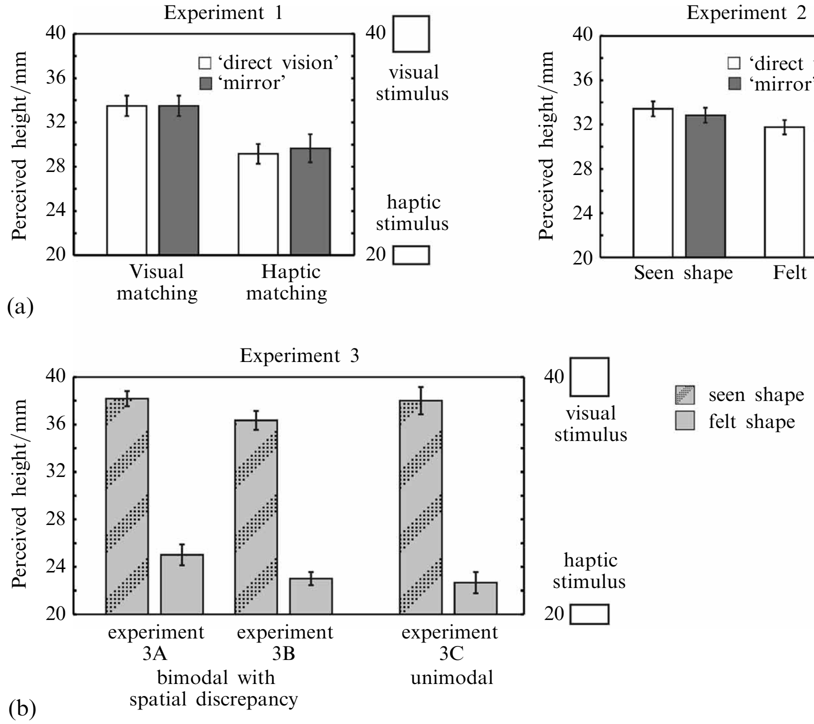


Figure 2. (a) Results of experiments 1 and 2. White bars show the perceived height obtained when participants directly look at the object they grasp (visual and haptic shape information is presented at a common location). Black bars are the results for the mirror condition, that is when visual and haptic inputs are spatially discrepant but participants know that they arise from the same object. (b) Results of experiment 3. Grey bars with black stripes represent the perceived height of the seen object. Solid grey bars show the perceived height of the felt object. The actual height of the visual object was 40 mm and that for the haptic object was 20 mm. Error bars represent standard error of the mean across participants.

of response to provide—visual or haptic matching. Therefore, this effect does not simply reflect a bias towards the attended modality. Rather, this difference in the reported percept as a function of matching condition suggests that the bimodal percept is not completely fused.

Most importantly, the shape percepts observed in 'direct vision' and 'mirror' conditions did not differ significantly ($F_{1,46} < 1$, $p > 0.77$, see figure 2a). Equally strong mutual biasing effects were observed in the two conditions. These findings suggest that visual and haptic information is integrated when participants have knowledge about the common origin of seen and felt shape information, irrespective of whether signals are spatially coincident or discrepant.

3 Experiment 2

In experiment 1 participants' task was to report the perceived shape. This instruction to report the shape of the object may have promoted integration. Furthermore, with this task instruction it is unclear how participants would behave if visual and haptic information was not fused. Possibly, some participants would report the seen shape while others would report the felt shape. This could lead to the same result pattern and thus 'feign' an integration effect. Therefore, we repeated experiment 1 and changed task instructions. We instructed participants to either report the visual or the haptic shape percept. As in experiment 1 we compared participants' shape percept in 'mirror' and 'direct vision' conditions. If integration breaks down, we would expect participants' shape percept to be close or identical to the actual visual stimulus when asked for the seen shape, and likewise when asked for the felt shape. If, on the other hand, discrepant signals are integrated when participants know that they come from a common source, one would expect the bimodal shape percept to be still in-between the visually and haptically specified shapes, despite explicit instructions to report either the felt or the seen shape. That is, the shape percepts should not differ across 'mirror' and 'direct vision' conditions.

3.1 *Method*

3.1.1 *Participants.* Two groups of forty-eight participants (forty-one males and fifty-five females) with normal or corrected-to-normal vision participated in experiment 2. All participants were naive to the purpose of the experiment and did not participate in experiment 1. Average age was 26 years (range 18 – 53 years).

3.1.2 *Stimuli and procedure.* The stimuli and setup were the same as in experiment 1. Again, all participants performed only two trials. In one trial they directly looked at the visual standard stimulus ('direct vision'), whereas in the other trial they viewed the visual shape through the mirror ('mirror' condition). Subsequent to the exploration phase, we instructed one group of participants ($n = 48$) explicitly to report the felt shape, whereas the other group ($n = 48$) had to report the seen shape. In both the seen shape and the felt shape conditions half of the participants visually selected a match from the comparison stimuli and the other half haptically selected a matching comparison.

3.2 *Results and discussion*

The results are shown in figure 2a (right panel). A repeated-measures ANOVA was conducted with within-participants factor vision ('direct vision' and 'mirror') and between-participants factor task ('seen shape' versus 'felt shape'). Because there was no significant difference between visual and haptic matching, we averaged data across the matching conditions. In both viewing conditions (report 'seen shape' versus 'felt shape') the shape percept was influenced by the shape presented in the task-irrelevant modality. This result is in agreement with Bresciani et al (2006) and indicates that visual and haptic shape percepts are automatically integrated even when the sensory input from one modality is task-irrelevant. The shape percept provided when participants were asked to report the seen shape (mean perceived height: 33.13 mm) differed significantly from the percept when participants were asked to report the felt shape (mean perceived height: 31.33 mm) ($F_{1,94} = 4.613$, $p < 0.035$). That is, participants' shape estimates were biased more towards the actual visual input (40 mm) when they were asked for the seen shape, and more towards the actual haptic input (20 mm) when they were asked for the felt shape. However, the difference $\Delta = 1.78$ mm between visually and haptically perceived shape is very small relative to the size of the sensory conflict (20 mm). The bimodal shape percepts are still well in-between the actual visual and haptic inputs and not predominantly biased towards one or the other sensory input as would be expected if integration breaks down and the signals are perceived independently. That is, even though this slight difference in perceived shape when asking for felt as opposed to seen shape indicates that the signals are not completely fused, there is a strong interaction between the signals indicating integration. Most importantly, the shape percepts obtained in 'direct vision' and 'mirror' conditions again did not differ from one another ($F_{1,94} = 1.459$, $p > 0.23$). The fact that we observed the same mutual biasing effect in the 'mirror' condition provides further evidence for sensory integration in this condition. That is, the integration effect could be observed even when we emphasised the difference between visual and haptic shape by explicitly asking participants to report only one or the other sensory input.

4 Experiment 3

The two previous experiments indicate that multisensory integration of spatially discrepant signals can occur if knowledge about the common origin of visual and haptic information is available. However, to be able to finally draw this conclusion, we still have to demonstrate that integration does indeed break down when participants sense two signals at discrepant locations. We conducted two control experiments in which we presented two different visual and haptic objects at clearly discrepant locations. In the first control experiment (experiment 3A), the visual and haptic objects were laterally displaced by 25 cm. In experiment 3B, our aim was to reproduce the spatial configuration of the mirror condition as close as possible. That is, the visual and haptic objects were presented in exactly the same spatial arrangement as in the mirror condition of the first two experiments. Participants were aware that they were presented with two distinct objects. Finally, we needed estimates of the apparent unimodal visual and haptic shape which would serve as a baseline in case the signals are not integrated. We therefore conducted a further experiment (experiment 3C) and asked participants to judge the shape of either a unimodal visual or haptic standard stimulus independently.

4.1 *Method*

4.1.1 *Participants.* Sixty participants (twenty-one males and thirty-nine females) with normal or corrected-to-normal vision participated in the experiment. All participants were naive to the purpose of the experiment and did not participate in any of the previous experiments.

4.1.2 *Stimuli and procedure.* Participants were presented with two objects: one object that could be seen and one that could be touched. In experiments 3A and 3B, the visual and haptic objects were presented simultaneously, whereas in experiment 3C either only the visual or only the haptic object was presented at a time.

In experiment 3A, two 20 mm × 40 mm plastic rectangles (same as in previous experiments) were mounted below the distorting plano-convex cylindrical lens, laterally separated from one another by 25 cm. The box in which the lens was mounted was 40 cm long and thus covered both objects (see figure 1a). Participants haptically explored the right (unseen) object while they saw the optically distorted object (40 mm × 40 mm) on the left. The right half of the lens was covered with an opaque sheet of paper to prevent sight of the haptic stimulus. In experiment 3B, participants felt a 20 mm × 40 mm plastic rectangle (haptic object) that was mounted below the lens (covered with an opaque sheet of paper) exactly as in experiments 1 and 2. They simultaneously saw a second rectangle 40 mm × 40 mm which was mounted in the same position and orientation as it could be seen in the mirror before. That is, the spatial separation between the two objects was the same as in the two main experiments. Twenty-four participants participated in experiment 3A and in experiment 3B. They performed two trials. In one trial, participants were asked to report the shape of the felt object. In the other trial, they reported the seen shape. The order of conditions was counterbalanced. The perceived shape was always reported by visually selecting a matching comparison (the same set of comparison objects as in experiments 1 and 2).

In experiment 3C, a subset of twelve participants was presented with two consecutive trials in counterbalanced order. Here we used the same stimuli (20 mm × 40 mm) and spatial arrangement as in experiment 3A. In one trial, participants viewed the standard stimulus through the distorting lens (visual shape: 40 mm × 40 mm) but were not allowed to touch it. In the other trial, they felt the probe object. Participants reported the perceived shape directly after each trial by visually selecting a comparison that matched the perceived shape.

4.2 *Results and discussion*

The results are shown in figure 2b. In experiments 3A and 3B the percept of the visual stimulus was biased mostly towards the actual visual input, while the percept of the haptic stimulus was almost completely dominated by touch. That is, the influence of touch on the perceived visual shape seems to be eliminated when participants are explicitly instructed to report the seen shape, and vice versa for the effect of vision on touch. This is even more apparent when comparing the results of experiments 3A and 3B to the unimodal visual and haptic shape percept determined in experiment 3C. The reported seen and felt shapes in experiments 3A and 3B do not differ significantly from the unimodal visual and haptic shape percepts in experiment 3C. We conducted two-tailed two-sample t-tests comparing the perceived height of the visual and haptic objects across experiments. None of the comparisons revealed a significant difference ($p > 0.059$ for all comparisons). These findings show that integration does indeed break down when spatial discrepancies are introduced such as in experiments 3A and 3B. In all three control experiments, the difference between the visual and the haptic shape percept was significant (experiment 3A: $t_{23} = 10.834$, $p < 0.0001$; experiment 3B: $t_{23} = 13.991$, $p < 0.0001$; experiment 3C: $t_{11} = 11.127$, $p < 0.0001$; two-tailed paired-sample t-test).

Consistent with Miller (1972) the unimodal haptic and visual shape percepts (experiment 3C) were not completely veridical but slightly shifted towards the middle of the range of comparison objects. This small bias is possibly due to the so-called range effect (eg Hollingworth 1910; Poulton 1975). These studies discovered a tendency for high values to be underestimated and for low values to be overestimated while intermediate values tended to be judged correctly. In other words, this effect may be caused by the participants' tendency to avoid floor and ceiling of the range. Note that this effect is irrelevant for the interpretation. Relevant for the interpretation of our results is only the comparison of the experimental data from experiments 3A and 3B with the baseline performance from experiment 3C. This comparison is the decisive factor for allowing conclusions whether the signals were integrated.

5 General discussion

In the present study we found that spatially discrepant visual and haptic shape information is integrated when participants know that vision and touch provide redundant information about the same object. This effect was observed independently of whether participants were instructed to report the shape of the object (experiment 1) or to report the felt or seen shape (experiment 2).

This finding is in agreement with previous research showing that crossmodal interactions (eg visual – proprioceptive adaptation: Welch 1972; visual – tactile integration of size information: Miller 1972) depend on participants' knowledge about object identity.

Interestingly, in our experiment 2, shape percepts were influenced by information in the task-irrelevant modality, even when one signal was (explicitly) task-irrelevant. This suggests that sensory information is automatically integrated across modalities. This finding agrees with Derrick and Dewar (1970) who found a visually induced bias on haptic size perception even when participants were informed that vision and touch might signal objects differing in size. This further suggests that multisensory information is integrated in an automatic fashion.

On the other hand, the automatic nature of multisensory integration (eg Bertelson et al 2000; Vroomen et al 2001) appears to be at odds with the observation that multisensory integration depends on cognitive factors such as knowledge about a common source. We hypothesise that the system first has to decide whether or not two signals come from a common source and should therefore be integrated (ie solve the correspondence problem). At this stage, knowledge about object identity can influence integration.

Another question is how this knowledge of unity is mediated. We speculate that in our experiment, this knowledge was most likely mediated by perceptual-motor coherence related to the fact that the explorative hand movements were visible. From our results, we cannot draw any conclusion on whether higher-level cognitive knowledge (eg mere instructions whether or not two inputs provide information about the same object) can also influence (facilitate or suppress) integration when there are no supporting lower level spatial and temporal cues. This speculation seems to be supported by Welch's (1972) study in which participants were probably led to believe that the seen hand was their own hand because the foreign hand was moving in synchrony with self-generated movements.

Rock and Victor (1964) and many others (eg Derrick and Dewar 1970; McDonnell and Duffett 1972; Miller 1972) precluded a direct view of the hand while exploring the object because they assumed that if participants were allowed to see their (distorted) hand they could become aware of the intersensory discrepancy, which in turn could reduce or eliminate the mutual sensory bias. Interestingly, here participants integrate multisensory signals even though they can see their visually distorted hand and thus should be aware that the visual input is not veridical. We speculate that this is due to the automatic nature of integration (eg Bresciani et al 2006).

In a number of other studies (Kinney and Luria 1970; Over 1966), including this one, participants were allowed to see their hand but still an effect of vision on haptics was observed. Welch and Warren (1980) postulated that the intersensory bias may actually be facilitated in such a situation owing to the strong assumption of unity resulting from a direct view of the hand. This is also supported by the present study where we created an assumption of unity by allowing participants to see their hand exploring the object. The spatial arrangement and the visual and haptic shapes did not differ between experiments 1 and 2, where signals were integrated, and the control experiment 3B. What differed was that in experiments 1 and 2 participants saw their hand exploring the object. Therefore, we hypothesise that this may be a key factor mediating knowledge about a common source.

Here we measured in two separate sessions (i) the influence of vision on perceived haptic shape and (ii) the influence of touch on perceived visual shape (see experiment 2). The participants' response when asked to report seen and felt shape differed slightly. If signals had been completely fused, the reports should have been independent of whether participants were asked for seen or felt shape. On the other hand, if the two percepts (seen and felt shape) had been independent (not integrated at all) there should have been no mutual bias between the two sensory modalities but instead the reported seen and felt shape should have been the same as the unimodal felt and seen shape (experiment 3C). What we actually found is neither complete fusion nor independence of the signals. It seems therefore reasonable to assume that there is a continuum between complete fusion and independence, in which we can find more or less mutual influence between the sensory modalities. Large discrepancies between the sources of information (spatial or temporal discrepancies or discrepancies of other object properties) may lead to less interaction between the signals. Recently Ernst (2005) reported a Bayesian model that formalised this continuum between independence and fusion by incorporating prior knowledge about object identity which he called the coupling prior (see also Bresciani et al 2006; Roach et al 2006; Shams et al 2005). According to this idea only congruent stimuli would be fused completely. In our experiments we necessarily had to introduce conflicts between visual and haptic shapes in order to determine the relative influence of touch on vision and vice versa and it seems reasonable that owing to this shape conflict we did not find complete fusion of the signals.

To summarise, we found that visual and haptic shape information is automatically integrated when participants have prior knowledge about the object identity. Such knowledge seems to be a facilitatory factor of multisensory integration which can even overcome large spatial discrepancies that lead to a breakdown of integration otherwise.

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